Experimental Report

22/01/2014

Proposal:	**5-42-338**	**Council:**	4/2012
Title:	Magnetization relaxation in magnetically and sterically anisotropic nanocomposites		

This proposal is resubmission of: 5-42-269

Researh Area: Physics

Main proposer: **DISCH SABRINA**

Experimental Team: DISCH SABRINA

Local Contact: WIEDENMANN Albrecht

Samples: FePt@MnO nanoparticle dimers, dispersed in d8-toluene

Instrument	Req. Days	All. Days	From	To
D22	3	2	02/11/2012	04/11/2012

Abstract:

We propose static and stroboscopic polarized SANS measurements on magnetically and sterically anisotropic Janus nanoparticles. The aim of the experiment is to investigate the influence of shape anisotropy and exchange bias (induced by interaction of the FePt and MnO subunits of the hetero-dimers) on both the surface spin canting of the FePt domain and the magnetization relaxation of the particles subject to an oscillating magnetic field. The stroboscopic and static polarized SANS techniques are well exploited at the D22 instrument.
As a result, we expect to gain precise information on the spin structure and magnetization dynamics in such anisotropic nanocomposites. This will be very valuable for future investigations on the coupling of different physical properties in Janus particles containing magnetic and polar subunits. The understanding of such fundamental nanomagnetic properties promises to contribute to the development of emerging multifunctional nanomaterials for future applications.

Magnetization relaxation in magnetically and sterically anisotropic nanocomposites

Magnetic nanoparticles exhibit unique physical properties as compared to the bulk material, with technological applications in *e.g.* magnetic data storage or biomedical applications depending on magnetic anisotropy and superparamagnetic relaxation [1]. Combining nanoparticles with different physical properties leads to novel materials with multiple functionalities [2], such as coexistence of magnetic and electric or optical properties. For possible applications of such multifunctional materials, the detailed understanding of the coupling of the magnetization relaxation and the different properties is required. Janus nanoparticles consisting of ferro- and antiferromagnetic subunits of different size provide tunable exchange bias effect and shape anisotropy. Such systems are promising for materials with tailored magnetization relaxation properties. Here, we carried out a time-resolved small-angle neutron scattering study on FePt@MnO nano-hetero-particles in an oscillating magnetic field, in order to elucidate the influence of the anisotropic shape and exchange bias on the Néel relaxation and Brownian motion.

The nanoparticle dimers under study, based on epitaxial attachment of FePt and MnO nanoparticles, are anisotropic in shape and carry net magnetic moments. The particle sizes of the FePt and MnO subunits can be tuned within a range of 3 to 6 nm and 9 to 17 nm, respectively. The samples have been characterized by transmission electron microscopy (TEM) and X-ray diffraction. DC magnetization measurements reveal strong interactions between the ferromagnetic FePt and the antiferromagnetic MnO domains, resulting in increased remanent and saturation magnetization, coercivity, and blocking temperature, as well as exchange bias [3].

In our microscopic study, we intended to separate the Néel and Brownian relaxation contributions in order to gain information on the influence of the FePt-MnO interface on the Néel relaxation. We expected major effects of a different subunit size ratio of the nano-hetero-particles on the magnetic relaxation due to variation of both shape anisotropy and exchange bias. Furthermore, the spatial resolution of the SANS technique should give information on the surface spin canting in the FePt domain and possible different relaxation effects in the nanocomposite subunits.

Time-resolved small-angle neutron scattering was performed on FePt@MnO nano-hetero-particles dispersed in d_8-toluene. An oscillating magnetic field of 20 mT was applied with frequencies between 50 and 400 Hz, and the resulting small angle scattering was collected continuously in $n = 100$ time channels of widths $\Delta t = (n\nu)^{-1}$ in a momentum range up to $Q_{max} = 0.15$ Å^{-1}. Such an experimental setup has been used at D22 in a time resolved study of magnetic structure factors [4]. The availability of polarized neutrons at D22 was an important requirement for this study as it allows

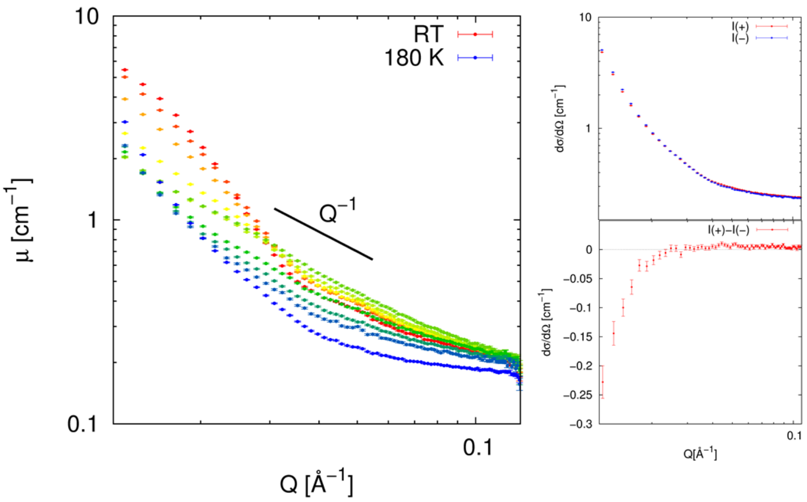

Figure 1: Temperature dependent SANS by FePt@MnO Janus nanoparticles upon cooling from room temperature to 180 K (left) and magnetic SANS at 180 K (right).

determining the phase shift of the scattering response with respect to the inducing field at the reversal of the magnetic field [5]. In view of the recent polarized SANS study of the same nanoparticles revealing a negligible magnetic scattering cross section at ambient temperatures (experimental report INTER-245), we carried out the time-resolved study at lower temperatures, ranging from 300 K to 180 K. Temperature-dependent polarized SANS measurements on FePt@MnO Janus nanoparticles are presented in Figure 1. We observe a substantial variation of the scattering signal upon cooling in an oscillating magnetic field. Even at the lowest achieved temperature, the magnetic scattering signal is small, thus not allowing a time-resolved study.

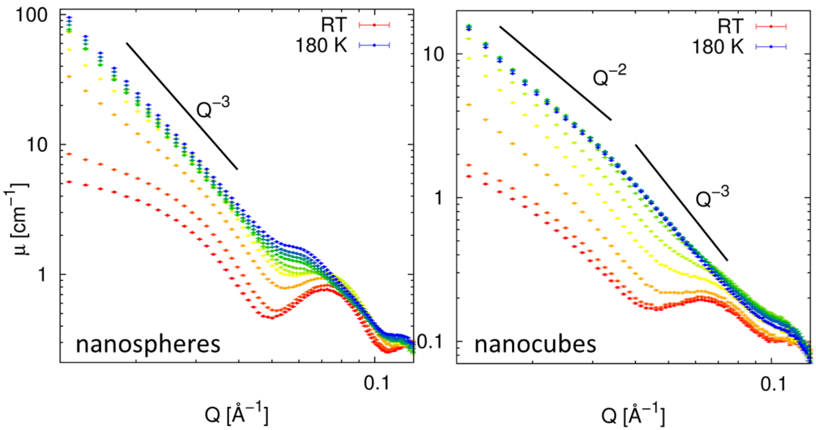

Figure 2: Temperature-dependent SANS by iron oxide nanospheres (left) and nanocubes (right) upon cooling from room temperature to 180 K.

In order to carry out time-resolved SANS measurements on nanoparticles exhibiting a stronger magnetic scattering behavior, we also measured iron oxide nanoparticles of spherical and cubic shape. These samples have been studied intensely using static small-angle scattering techniques at ambient temperatures, and their morphology is thus well known [6]. The temperature dependent SANS measurements measured during this experiment are presented in Figure 2. For both samples, a significant change in the Q dependent SANS signal is again observed upon cooling. We attribute the change in the wide Q range, mainly a shift of the form factor minima, to the temperature dependent variation of the density of toluene, resulting in a variation of the core-shell-matrix contrasts. At lower temperatures, a strong increase in scattering intensity in the low Q range is observed, which is attributed to a structure factor resulting from aggregation of the particles in the cooling dispersion. Along with this increasing structure factor, we also observe a variation of the nuclear-magnetic cross-term for both samples, presented in Figure 3. The variation of magnetic contrast indicates that the amplitude of the time-resolved magnetization oscillations cannot be quantitatively compared for different temperatures. Time-resolved data of these samples at ambient and lowest temperatures is given in Figure 4. The negligible time-shift of the scattering signal between ambient and lowest temperatures indicates that the particle magnetization follows the inducing magnetic field in the entire studied temperature and frequency range. In order to observe a significant variation of Brownian and/or Néel

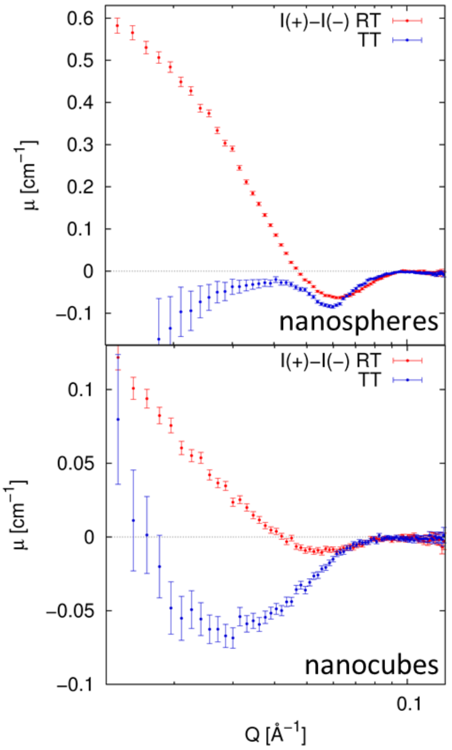

Figure 3: nuclear-magnetic cross term by iron oxide nanospheres and nanocubes.

relaxation in the studied samples, lower accessible temperatures as well as much higher frequencies of the inducing magnetic field are required. These may be achieved using the newly installed TISANE technique at D22.

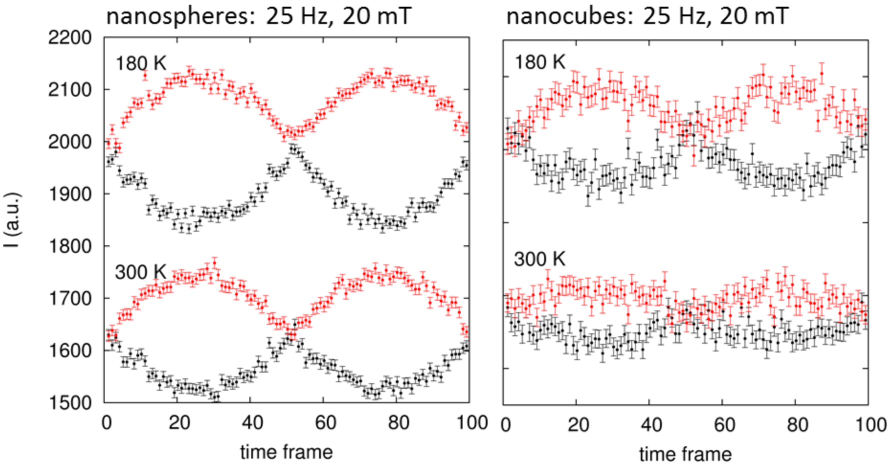

Figure 4: Time-resolved polarized SANS by iron oxide nanospheres and nanocubes. The I(+) (black) and I(-) (red) scattering intensity integrated in a sector box at 0.05 $Å^{-1} < Q < 0.065 Å^{-1}$ perpendicular to the alternating magnetic field direction is shown.

References:

[1] Q. A. Pankhurst, J. Connolly, S. K. Johnson, J. Dobson, *J. Phys. D: Appl. Phys.* **36**, R167 (2003).

[2] H. Zeng, S. Sun, *Adv. Funct. Mater.***18**, 391 (2008).

[3] T. Schladt *et al.*, *Chem. Mater* **24**, 525 (2012).

[4] A. Wiedenmann *et al.*, *Phys. Rev*. B **77**, 184417 (2008).

[5] A. Wiedenmann *et al.*, *Phys. Rev. B* **84**, 214303 (2011).

[6] S. Disch *et al.*, *New J. Phys.* **14**, 013025 (2012).